

U.S. GODAE: Global Ocean Prediction with the Hybrid Coordinate Ocean Model (HYCOM)

Eric P. Chassignet

Center for Ocean-Atmospheric Prediction Studies, Florida State University
phone: (850) 644-4581 fax: (850) 644-4841 email: echassignet@coaps.fsu.edu

Award Number: N00014-04-1-0676

<http://www.hycom.org>

LONG-TERM GOALS

A broad partnership of institutions is collaborating in developing and demonstrating the performance and application of eddy-resolving, real-time global and basin-scale ocean prediction systems using the HYbrid Coordinate Ocean Model (HYCOM). These systems are to be transitioned for operational use by the U.S. Navy at both the Naval Oceanographic Office (NAVOCEANO), Stennis Space Center, MS, and the Fleet Numerical Meteorology and Oceanography Center (FNMOC), Monterey, CA, and by NOAA at the National Centers for Environmental Prediction (NCEP), Washington, D.C. The systems will run efficiently on a variety of massively parallel computers and will include sophisticated, but relatively inexpensive, data assimilation techniques for assimilation of satellite altimeter sea surface height (SSH) and sea surface temperature (SST) as well as in-situ temperature, salinity, and float displacement.

The partnership represents a truly broad spectrum of the oceanographic community, bringing together academia, federal agencies, and industry/commercial entities, spanning modeling, data assimilation, data management and serving, observational capabilities, and application of HYCOM prediction system outputs. The institutions participating in this Partnership have long histories of supporting and carrying out a wide range of oceanographic and ocean prediction-related research and data management. All institutions are committed to validating an operational hybrid-coordinate ocean model that combines the strengths of the vertical coordinates used in the present generation of ocean models by placing them where they perform best. This collaborative partnership provides an opportunity to leverage and accelerate the efforts of existing and planned projects, in order to produce a higher quality product that will collectively better serve a wider range of users than would the individual projects. In addition to operational eddy-resolving global and basin-scale ocean prediction systems for the U.S. Navy and NOAA, respectively, this project offers an outstanding opportunity for NOAA-Navy collaboration and cooperation ranging from research to the operational level.

This effort is part of a 5-year (FY04-08) multi-institutional National Ocean Partnership Program (NOPP) project which includes the Florida State University (E. Chassignet, A. Srinivasan), U. of Miami (G. Halliwell, M. Iskandarani, T. Chin, A. Mariano, Z. Garraffo), NRL/STENNIS (H. Hurlburt, A. Wallcraft, J. Metzger, B. Kara, J. Cummings, G. Jacobs, H. Ngodock, C.A. Blain, P. Hogan, J. Kindle), NAVOCEANO (F. Bub), FNMOC (M. Clancy), NRL/MONTEREY (R. Hodur, J. Pullen, P. May), NOAA/NCEP/MMAB (D.B. Rao, C. Lozano), NOAA/NOS (F. Aikman), NOAA/AOML (C. Thacker), NOAA/PMEL (S. Hankin), Planning System Inc. (O.M. Smedstad), NASA-GISS (R. Bleck), SHOM (R. Baraille), LEGI (P. Brasseur), OPeNDAP (P. Cornillon), U. of S. Mississippi (W. Schmitz), U. of N. Carolina (C. Werner), Rutgers (J. Wilkin, D. Haidvogel), U. of S. Florida (R.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 30 SEP 2007		2. REPORT TYPE Annual		3. DATES COVERED 00-00-2007 to 00-00-2007	
4. TITLE AND SUBTITLE U.S. GODAE: Global Ocean Prediction With The Hybrid Coordinate Ocean Model (HYCOM)				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Florida State University, Center for Ocean-Atmospheric Prediction Studies, Tallahassee, FL, 32306				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES code 1 only					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 12	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Weisberg), Fugro-GEOS/Ocean Numerics (D. Szabo, R. Stephens), Horizon Marine Inc. (J. Feeney, S. Anderson), ROFFS (M. Roffer), Orbimage (L. Stathoplos), Shell Oil Company (M. Vogel), ExxonMobil (O. Esenkov).

OBJECTIVES

The partnership is addressing the Global Ocean Data Assimilation Experiment (GODAE) objectives of three-dimensional (3D) depiction of the ocean state at fine resolution in real-time and provision of boundary conditions for coastal and regional models. It will also provide the ocean component and oceanic boundary conditions for a global coupled ocean-atmosphere prediction model. It will make these results available to the GODAE modeling community and general users on a 24/7 operational basis via a comprehensive data management strategy.

APPROACH AND WORK PLAN

HYCOM development is the result of collaborative efforts among the University of Miami, the Naval Research Laboratory (NRL), and the Los Alamos National Laboratory (LANL), as part of the multi-institutional HYCOM Consortium for Data-Assimilative Ocean Modeling. This effort was funded by the National Ocean Partnership Program (NOPP) in 1999 to develop and evaluate a data-assimilative hybrid isopycnal-sigma-pressure (generalized) coordinate ocean model (Bleck, 2002; Chassignet et al., 2003; Halliwell, 2004). HYCOM has been configured globally and on basin scales at $1/12^\circ$ (~ 7 km mid-latitude) resolution, and regionally at $1/25^\circ$ (~ 3.5 km mid-latitude) resolution. More details can be found at <http://www.hycom.org> and in the separate ONR report by H. Hurlburt.

While HYCOM is a sophisticated model, including a large suite of physical processes and incorporating numerical techniques that are optimal for dynamically different regions of the ocean, data assimilation is still essential for ocean prediction a) because many ocean phenomena are due to flow instabilities and thus are not a deterministic response to atmospheric forcing, b) because of errors in the atmospheric forcing, and c) because of ocean model imperfections, including limitations in resolution. One large body of data is obtained remotely from instruments aboard satellites. They provide substantial information about the ocean's space-time variability at the surface, but they are insufficient by themselves for specifying the subsurface variability. Another significant body of data is in the form of vertical profiles from XBTs, CTDs, and profiling floats (*e.g.*, ARGO). Even together, these data sets are insufficient to determine the state of the ocean completely, so it is necessary to exploit prior knowledge in the form of statistics determined from past observations as well as our understanding of ocean dynamics. We combine all sources of information synergistically to produce the best possible depiction of the evolving ocean. Several techniques for assimilating data into HYCOM are either in place or under development (see separate ONR report by A. Srinivasan).

In order to increase the predictability of coastal regimes, several partners within the HYCOM consortium are developing and evaluating boundary conditions for coastal prediction models based on the HYCOM data assimilative system outputs (see section c of the results section and separate ONR reports by R. Weisberg and G. Halliwell). The inner nested models may or may not be HYCOM, so the coupling of the global and coastal models needs to be able to handle unlike vertical grids. Coupling HYCOM to HYCOM is now routine via one-way nesting (Zamudio et al., 2006). Coupling HYCOM to other models, such as the Navy Coastal Ocean Model (NCOM) or the Regional Ocean Model

System (ROMS), has already been demonstrated, while coupling of HYCOM to unstructured grid/finite element models is still in progress.

RESULTS

Funding was received for the FSU, U. of Miami, PSI, USF, UNC, OPeNDAP, Rutgers, and W. Schmitz. We report here on some of the progress made during FY 07.

a) Global ocean forecasting system:

NCODA Implementation:

The Navy Coupled Ocean Data Assimilation (NCODA) (Cummings, 2005) system is being used as the assimilation technique in the global HYCOM experiments. The NCODA system is a fully three-dimensional multivariate optimum interpolation system. The three-dimensional ocean analysis variables include temperature, salinity, geopotential and the vector velocity components (T, S, U, V), which are all analyzed simultaneously. In support of HYCOM, a new analysis variable was added to NCODA that corrects the model layer pressure of the hybrid vertical coordinates. The NCODA horizontal correlations are multivariate in geopotential and velocity, thereby permitting adjustments (increments) to the mass fields to be correlated with adjustments to the flow fields. The velocity adjustments are in geostrophic balance with the geopotential increments, and the geopotential increments are in hydrostatic agreement with the temperature and salinity increments. Either the Cooper and Haines (1996) technique or synthetic T & S profiles (Fox et al., 2002) can be used for downward projection of SSH and SST. The Cooper and Haines (1996) technique is used for downward projection of the SSH data in the experiments with the global model. The present implementation interpolates the HYCOM vertical coordinate to z-space, performs the NCODA analysis, and then maps the z-level NCODA T, S U, V and layer pressure analysis increments to the appropriate HYCOM vertical coordinate. The HYCOM update program applies the temperature and salinity analysis increments in the model mixed layer, and applies the layer pressure analysis increments in the isopycnal part of the domain to correct the model interface layer pressures. The incremental updating scheme is used so that a fraction of the analysis increments can be added to the HYCOM forecast variables at each model time step. Typically the increments are added over a 6 hour window. The NCODA analysis software has been upgraded so that it can run both in the Mercator and the bipolar Arctic part of the HYCOM domain, see below.

1/12° Global HYCOM:

The first hindcast experiment with the 1/12° Global HYCOM using NCODA as the assimilation technique has finished. In this experiment the NCODA analysis was split into 12 overlapping regions covering the Mercator part of the global HYCOM grid. The experiment was initialized on 2 November 2003 using a model field from a run without data assimilation. A NCODA analysis was performed every 24 hours, assimilating all available observations within 12 hours of the analysis time except for the altimeter data where a 72 hour time window was used. In order to assimilate the altimeter anomalies from the satellite altimeters, it is necessary to have a mean sea surface height field. In the current system a model mean from an atmospherically forced model experiment was used. The mean sea surface height was compared to available observations of the frontal location of the Kuroshio and the Gulf Stream and then modified using a rubber sheeting technique. It is important to have an

accurate frontal location for the assimilation to be successful in these regions. A validation of the results from the hindcast run is under way. The focus of the validation this year is the large scale circulation features, sea surface height variability and eddy kinetic energy, mixed layer depth, vertical profiles of temperature and salinity, sea surface temperature and coastal sea levels. As an example of this validation, figure 1a shows the SSH variability from the Modular Ocean Data Assimilation System (MODAS) analysis of altimeter observations and figure 1b shows the variability from HYCOM over the three years of the assimilative hindcast experiment. The variability compares well with what is observed. The model output from the hindcast experiment is available through the HYCOM consortium web page, <http://www.hycom.org>. See also the separate report by H. Hurlburt for additional metrics.

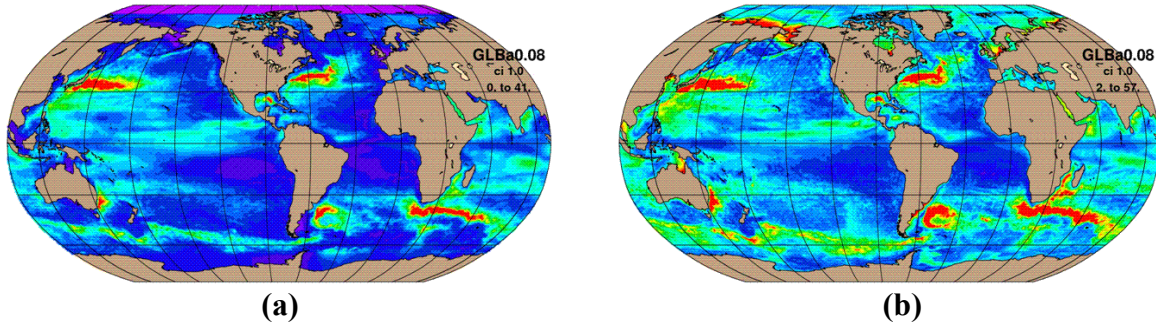


Figure 1. (a) The SSH variability from the MODAS analysis of available satellite altimeter observations for the period 1993-2006 and (b) the SSH variability from the 1/12° Global HYCOM domain over the time period 2004-2006, the three years of the assimilative hindcast.

A new set of 8 subdomains have been set up, see figure 2, so that the NCODA analysis can run in all parts of the global HYCOM grid. The analysis is split in 8 domains for computational efficiency. Each domain is run on a fraction of the total number of available processors so that each domain finishes at about the same time. A hindcast experiment using the new regions is underway. The first experiment will be a repeat of the previous hindcast experiment for the year 2005. The latest version of the HYCOM code is also used in this experiment. The new code can use a baroclinic time step that is twice as long as in the old version. The results from this experiment will be validated against observations as well as compared to the results from the initial hindcast.

A pre-operational nowcast/forecast system using the 1/12° global HYCOM has been running in near real-time since 22 December 2006 and in real-time since 16 February 2007. The model is running on 379 processors (24 nodes) on the IBM Power 5+ at the Naval Oceanographic Office using a part of the operational allocation on the machine. The daily run consists of a 5 day hindcast and a 5 day forecast and takes about ~15 wall clock hours. In the present implementation the NCODA analysis is performed at 18Z and the model is incrementally updated over the next 6 hours so that the data from the 18Z analysis is in the model at the 00Z nowcast. The real-time web page showing the results from the system can be found on the HYCOM consortium web page, <http://www.hycom.org>. The model output is also available through this web site. The model is routinely compared to both independent observations and observations that are used in the assimilation. An example of an independent observation comparison can be seen in figure 3a-b. These figures show the SSH in the Kuroshio and Gulf Stream region, respectively. The white/black line represents the frontal analysis of MCSST

observations performed at the Naval Oceanographic Office. A black line represents data more than four days old. The model is able to accurately depict the frontal position in these regions, showing most of the meanders indicated in the observations.

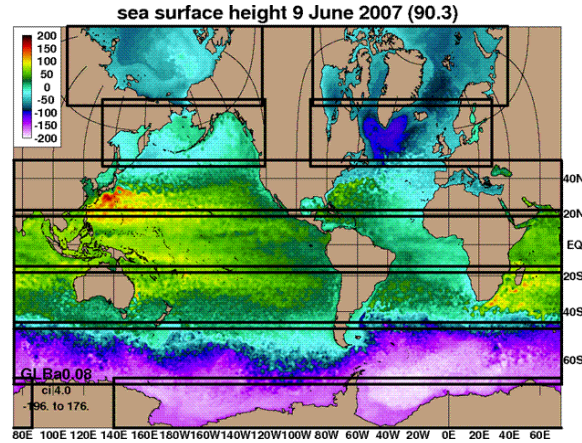


Figure 2. (a) The figure shows the SSH field from the 1/12° Global HYCOM domain on 9 June 2007 with the 8 regions for the NCODA analysis covering the global HYCOM grid.

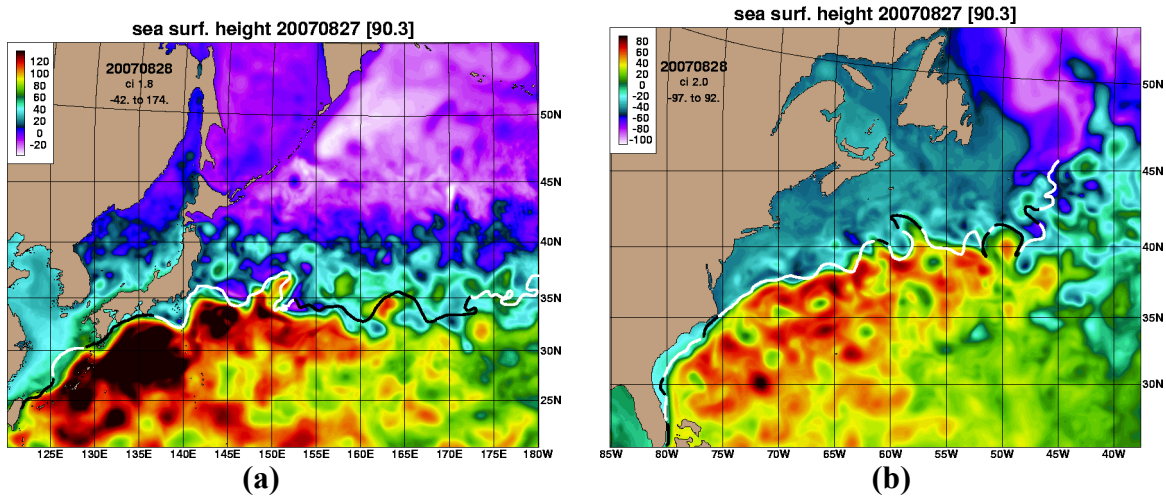


Figure 3. The SSH field from the 1/12° Global HYCOM domain on 27 August 2007 in the (a) Kuroshio region and (b) Gulf Stream region. The black line represents the frontal analysis of MCSST observation performed at the Naval Oceanographic Office. A black line represents data more than four days old.

b) Data management:

The HYCOM Data Distribution System effort (S. Hankin, A. Srinivasan, P. Cornillon) has had to address a number of distinct but coupled tasks: receiving model outputs from data providers; converting between formats as needed to meet data serving needs; providing data subsets to internal

HYCOM Consortium modelers for purposes of forcing downscaled (coastal) models; providing access to HYCOM outputs for interdisciplinary science and education needs in a variety of formats; providing an on-line environment to assist with validation and intercomparison of model runs. The main goal is to develop and implement a comprehensive data management and distribution strategy that allows easy and efficient access to HYCOM-based ocean prediction system outputs to (a) coastal and regional modeling sites, (b) to the wider oceanographic and scientific community including climate and ecosystem researchers, and (c) the general public especially students in middle and high schools. The basic idea consists of the setup of a web server that acts as a gateway to backend data management, distribution and visualization applications. These applications enable end users to obtain a broad range of services such as browsing of datasets, gif images, NetCDF files, FTP request of data etc. The HYCOM Data Sharing System is built upon two existing software components: the Open Project for a Network Data Access Protocol (OPeNDAP) and the Live Access Server (LAS). These tools and their use to distribute the data are described below. In the current setup, the OPeNDAP component provides the middleware necessary to access distributed data, while the LAS functions as a user interface and a product server. The abstraction offered by the OPeNDAP server also makes it possible to define a virtual data set that LAS will act upon, rather than physical files. An OPeNDAP “aggregation server” utilizes this approach to append model time steps from many separate files into virtual datasets.

The Hybrid Coordinate Ocean Model (HYCOM) consortium’s data service provides at the present time access to the following datasets:

1. 1/12 Global HYCOM simulation (Free run - currently the daily outputs of years 2003-2006 are available; will soon be extended to 2007)
2. 1/12 Global HYCOM daily hindcasts using the NCODA analysis (currently the years 2003-2004 as well as the period from April 2007 to present; 2005 to April 2007 is being added)
3. 1/12 Global HYCOM+NCODA real time daily 5-day forecast.
4. Near real-time 1/12° Atlantic Ocean prediction system output (June 2003 –Present)
5. Monthly mean 1/12° Pacific Ocean Simulation output (1978-2003)
6. Monthly mean 1/3° Atlantic Ocean simulation output (1980-2000)
7. Several 1/12° Gulf of Mexico simulations for inter-comparing data assimilation schemes (HYDAE)

The HYCOM Data service has been in operation for the last four years and has seen a steady increase in the user base. In the last year the service received approximately 20,000 hits per month. In addition to the numerous requests from educational institutes and researchers this service has been providing near real-time data products to several private companies in France, Portugal and the USA. A Storage Area Network (SAN) consisting of three servers consisting of 4 AMD dual core Opteron CPUs attached over fibre channel to 100 TB of SATA based storage has been recently purchased. In this system, the servers are configured in a high availability mode and runs a Global file system which will allow concurrent read/write requests from all the attached 24 CPU’s. The server design and overall operational philosophy includes high availability and high reliability features to allow for

uninterrupted use. For an overview of the capabilities of the server, the reader is referred to the separate ONR report by A. Srinivasan.

c) Boundary conditions for regional/coastal models

The horizontal and vertical resolution chosen for the above forecasting systems marginally resolves the coastal ocean (7 km at mid-latitudes, with up to 15 terrain-following (σ) coordinates over the shelf), but is an excellent starting point for even higher resolution coastal ocean prediction systems. The resolution should increase to $1/25^\circ$ (3-4 km at mid-latitudes) by the end of the decade. An important attribute of the data assimilative HYCOM simulations is therefore the capability to provide boundary conditions to regional and coastal models. In order to increase the predictability of coastal regimes, several partners within the HYCOM consortium are developing and evaluating boundary conditions for coastal prediction models based on the HYCOM data assimilative system outputs. As stated above, coupling HYCOM to other models, such as the NCOM or ROMS (see separate ONR report by R. Weisberg), has already been demonstrated and is now routine, while coupling of HYCOM to unstructured grid/finite element models is in progress.

During this past year, the U. of North Carolina group focused on two aspects: an improvement of the finite element mesh used to nest their coastal domain in the HYCOM solution (i.e., forced by HYCOM in a downscaling mode) and acceleration of the transition of the coastal circulation model from Quoddy to ADCIRC.

1. Transition to new FEM mesh. UNC became concerned about the validity of their South Atlantic Bight (SAB) regional model simulations (currently done with Quoddy), primarily owing to insufficient resolution seaward of the continental shelf. They generated a new mesh such that:

- Minimum resolution will keep the $1/12$ -degree resolution of the HYCOM simulation. This is particularly important to prevent deep ocean mesoscale eddies properly captured in the HYCOM simulations from being aliased to larger features oscillating at inertial period in Quoddy simulations.
- Enhanced resolution near the shelf break.
- Northern boundary extended to include Chesapeake and Delaware Bays. We have included these in order to be able to include outflows from the Bays into the domain and to have better overlap with Harvey Seim's HFR surface velocities from Cape Hatteras to beyond the mouth of Chesapeake Bay.
- Northern boundary extending offshore far enough to capture the complete envelope of likely Gulf Stream exit from the domain.

Two versions of the new mesh were produced by Rick Luettich's group at UNC. The first mesh contains very high resolution along the coastline and includes estuaries, islands, and tidal inlets (Figure 4). The second is the same, except that it has a continuous coastline. UNC anticipates that these changes, together with algorithmic changes in the treatment of the open boundaries, will significantly improve the baroclinic Quoddy runs.

Once Quoddy is running reliably on the new mesh, the SAB nowcast/forecast system will be re-implemented. The new system will use the new mesh, the new global HYCOM 1/12-degree simulations, and new NCEP meteorological forcing products. This system will serve as the basis of the climatological studies outlined previously. This work will use the continuous shoreline (no inlets or estuaries) version of the new mesh.

2. *Transition to ADCIRC.* UNC plans to transition to the use of ADCIRC for our regional model as soon as feasible. They are collaborating with Luettich (UNC) and Randy Kolar (U Oklahoma) as they work to produce a 3D baroclinic version of ADCIRC. A 4-day diagnostic run has been completed, and surface density and velocity fields are shown in Figure 5 (on an earlier mesh). They will switch our nowcast/forecast system and climatological runs to ADCIRC on the high-resolution version of the new mesh (including the estuaries and inlets), taking advantage of the speed of ADCIRC's parallelized version to complete this work.

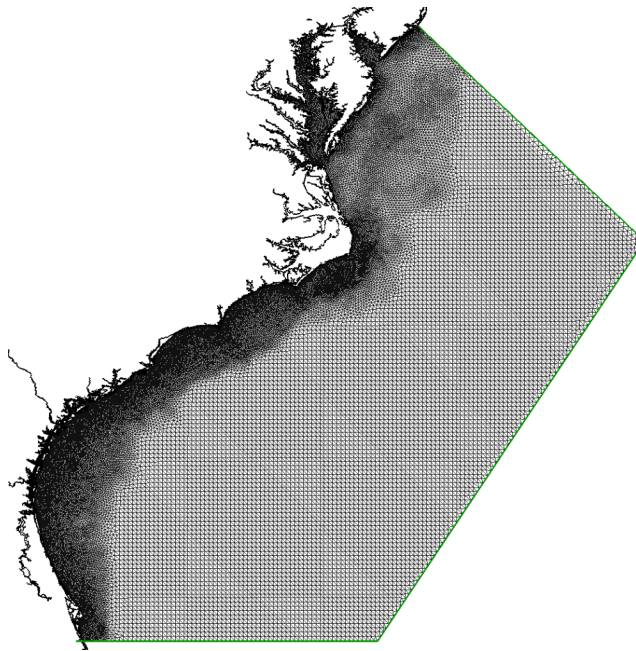


Figure 4. New finite element mesh of the South Atlantic Bight. Open-ocean resolution is a maximum of 1/12-degree and coastal islands, inlets and estuaries are resolved. A second version of this mesh with a continuous coastline will be used for Quoddy runs, and the full mesh will be used after the transition to ADCIRC.

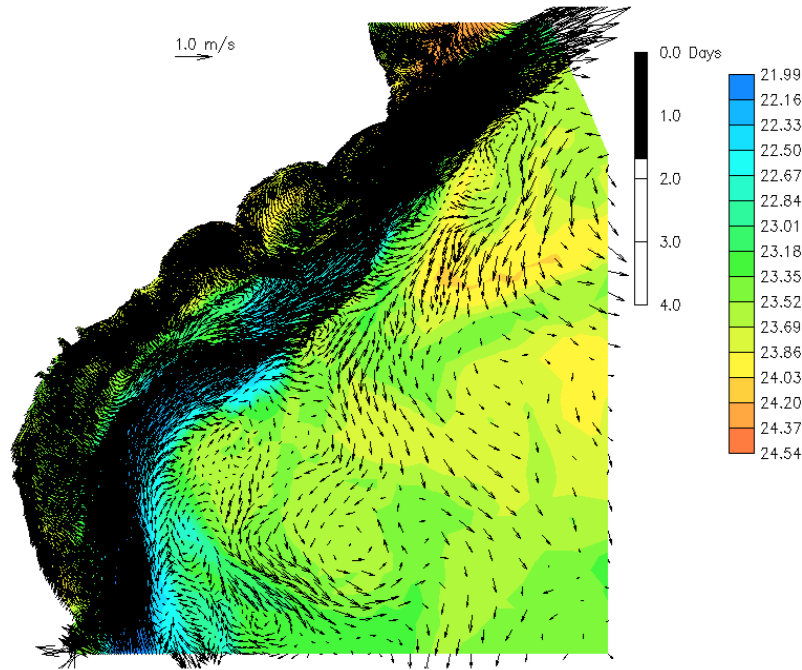


Figure 5. Top level velocity field 1.75 days into a 4-day diagnostic run of the 3D baroclinic version of ADCIRC. The colormap shows top level density anomaly (density field held constant for the diagnostic run). Initial conditions are from the 1/12-degree Atlantic HYCOM simulation and the FEM mesh is the original HYCOM/Quoddy SAB mesh (courtesy R. Kolar and K. Dresback, U. Oklahoma)

IMPACT/APPLICATIONS

Three-dimensional (3D) depiction of the ocean state at fine resolution in real-time and provision of boundary conditions for coastal and regional models in the context of the Global Ocean Data Assimilation Experiment (GODAE).

TRANSITIONS

None.

RELATED PROJECTS

This is a highly collaborative NOPP project with 24 partnering groups as listed above. Additionally, the project is receiving grants of super computer time from the DoD High Performance Computing Modernization Office and collaborates closely with the NOPP project led by G. Halliwell entitled “HYCOM Coastal Ocean Hindcasts and Prediction: Impact of Nesting in HYCOM GODAE Assimilative Hindcasts”.

REFERENCES

- Bleck, R., 2002: An oceanic general circulation model framed in hybrid isopycnic-cartesian coordinates. *Ocean Modelling*, **4**, 55-88.
- Chassignet, E.P., and Z.D. Garraffo, 2001: Viscosity parameterization and the Gulf Stream separation. In "From Stirring to Mixing in a Stratified Ocean". Proceedings 'Aha Huliko'a Hawaiian Winter Workshop. U. Hawaii. January 15-19, 2001. P. Muller and D. Henderson, Eds., 37-41.
- Chassignet, E.P., L.T. Smith, G.R. Halliwell, and R. Bleck, 2003: North Atlantic simulations with the HYbrid Coordinate Ocean Model (HYCOM): Impact of the vertical coordinate choice, reference density, and thermobaricity. *J. Phys. Oceanogr.*, **33**, 2504-2526.
- Cooper, M. and K. Haines, 1996. Altimetric assimilation with water property conservation. *J. Geophys. Res.*, **101 (C1)**, 1059-1077.
- Cummings, J.A., 2005. Operational multivariate ocean data assimilation. *Quart. J. Royal Met. Soc.*, **131**:3583-3604.
- Fox, D.N., W.J. Teague, C.N. Barron, M.R. Carnes and C.M. Lee, 2002. The Modular Ocean Data Assimilation System (MODAS). *J. Atmos. Oceanic Tech.*, **19**, 240-252.
- Halliwell, Jr., G.R., 2004: Evaluation of vertical coordinate and vertical mixing algorithms in the HYbrid-Coordinate Ocean Model (HYCOM). *Ocean Modelling*, **7**, 285-322.

PUBLICATIONS (2006-2007)

- Xu, X., Y.S. Chang, H. Peters, T.M. Özgökmen, and E.P. Chassignet, 2006: Parameterization of gravity current entrainment for ocean circulation models using a high-order 3D nonhydrostatic spectral element model. *Ocean Modelling*, **14**, 19-44.
- Cherubin, L.M., Y. Morel, and E.P. Chassignet, 2006: Loop Current ring shedding: The formation of cyclones and the effect of topography. *J. Phys. Oceanogr.*, **36**, 569-591.
- Peng, G., E.P. Chassignet, E.P., Y.O. Kwon, and S.C. Riser, 2006: Investigation of variability of the North Atlantic Subtropical Mode Water using profiling float data and numerical model output. *Ocean Modelling*, **13**, 65-85..
- Rothstein, L.M., J.J. Cullen, M. Abott, E.P. Chassignet, K. Denman, S. Doney, H. Ducklow, K. Fennel, M. Follows, D. Haidvogel, E. Hoffman, D. Karl, J. Kindle, I. Lima, M. Maltrud, C. McClain, D. McGillicuddy, J. Olascoaga, Y. Spitz, J. Wiggert, and J. Yoder, 2006: Modeling ocean ecosystems - the PARADIGM program. *Oceanography*, **19**, 16-45.
- Chassignet, E.P., and J. Verron (Eds.), 2006: *Ocean Weather Forecasting: An Integrated View of Oceanography*. Springer, 577 pp.
- Chassignet, E.P., H.E. Hurlburt, O.M. Smedstad, G.R. Halliwell, P.J. Hogan, A.J. Wallcraft, and R. Bleck, 2006: Ocean prediction with the Hybrid Coordinate Ocean Model (HYCOM). In: *Ocean Weather Forecasting: An Integrated View of Oceanography*, Chassignet, E.P., and J. Verron (Eds.), Springer, 413-426.
- Chassignet, E. P., H. E. Hurlburt, O. M. Smedstad, G. R. Halliwell, A. J. Wallcraft, E. J. Metzger, B. O. Blanton, C. Lozano, D. B. Rao, P. J. Hogan, and A. Srinivasan, 2006: Generalized vertical coordinates for eddy resolving global and coastal ocean forecasts. *Oceanogr.*, **19**, 20-31.
- Aretxabaleta, A., B.O. Blanton, H.E. Seim, F.E. Werner, J.R. Nelson, and E.P. Chassignet, 2007: Cold event in the South Atlantic Bight during summer of 2003: Model simulations and implications. *J. Geophys. Res.*, **112**, C05022, doi:10.1029/2006JC003903.

- Chassignet, E.P., H.E. Hurlburt, O.M. Smedstad, G.R. Halliwell, P.J. Hogan, A.J. Wallcraft, R. Baraille, and R. Bleck, 2007: The HYCOM (HYbrid Coordinate Ocean Model) data assimilative system. *J. Mar. Sys.*, 65, 60–83.
- Halliwell, G.R., L.K. Shay, S.D. Jacobs, O.M. Smedstad and E.W. Uhlhorn, 2007. Improving ocean model initialization for coupled tropical cyclone forecast models using GODAE nowcasts. *Monthly Weather Review*, in press.
- Chassignet, E.P., and D.P. Marshall, 2007: Gulf Stream separation in numerical ocean models. In "Eddy-Resolving Ocean Modeling", M. Hecht and H. Hasumi, Eds., AGU Monograph Series, in press.
- Hurlburt H.E., E.P. Chassignet, J.A. Cummings, A.B. Kara, E.J. Metzger, J.F. Shriver, O.M. Smedstad, A.J. Wallcraft, and C.N. Barron, 2007: Eddy-resolving global ocean prediction. In "Eddy-Resolving Ocean Modeling", M. Hecht and H. Hasumi, Eds., AGU Monograph Series, in press.
- Kara, A.B., A.J. Wallcraft, P.J. Martin, and E.P. Chassignet, 2007: Performance of mixed layer models in simulating SST in the Equatorial Pacific Ocean. *J. Geophys. Res.*, in press.
- Xu, X., E.P. Chassignet, J.F. Price, T.M. Özgökmen, and H. Peters, 2007: A regional modeling study of the entraining Mediterranean outflow. *J. Geophys. Res.*, in press.